Mr. Donovan read a paper on the Comparative Advantages of smelting Lead Ore by the Blast-hearth and the Reverberatory Furnace.

" Several methods are made use of in the docimastic art for reducing the ores of lead to the metallic state; one only is employed in the smelting-house, although there are some practical differences in the modes of carrying it into effect. The ore of lead which is most abundantly found and smelted in the British isles is galena, or sulphuret of lead; the object of the smelter is to deprive the ore of its sulphur, in order that the lead may be liberated in the metallic state. This object he effects by the conjoint action of heat and air. There are two methods of applying both,—by the reverberatory furnace and by the blast-hearth; and good judges are found to advocate the employment of each.

" A few years since I spent some time in Flintshire, amongst the smelting establishments, for the purpose of informing myself on the relative advantages of these two furnaces. I knew that in the north of England, and parts of Scotland, the blast-hearth is more in favour, and that it was the only furnace in use some years since in Yorkshire. In the whole extent of mining district, from Bagilt and Holywell to Mold and Halkin, there is not now one blast-hearth, none other save the reverberatory and slag-hearth being employed. In the memory of the present age there never had been a blast-hearth in Flintshire but one; and that, after having been used for some time, was abandoned. At Alston Moor, in Cumberland, the blast-hearth is still used, on account of the great length of land carriage of fuel.

" When the reverberatory furnace is to be employed, the ore, freed, as well as means permit, from extraneous matter, and pulverized, is extensively spread out on the floor of the furnace, and exposed to the action of heat and a current of air created by the draught of the chimney. Although the ore would bear any available temperature in close vessels, without

parting with its sulphur, it cannot endure both heat and the current without desulphuration. The lead, therefore, separates in the metallic state; any foreign matter which the ore contained melts along with the lead, and swims upon its surface. This matter, called scoria, or slag, would run off with the lead when the furnace is tapped, but for a process of coagulation or thickening, which it is made to undergo by sprinkling lime upon its surface. The slag is finally removed, and melted with more lime in another furnace, called the slag-hearth, urged by bellows, and then it affords an additional quantity of lead. The first run is called soft, or ore lead; the second is hard, or slag lead, and bears a somewhat lower price.

"The blast-hearth is a small furnace, constructed of a few blocks of cast iron placed upon a bed of masonry, in such a manner as to include a square shallow well, in which is contained the burning fuel, consisting, according to circumstances, of wood, charcoal, common coal, coke, or turf, or all of these. A double bellows, of considerable size, worked by a water-wheel, or by manual labour, assisted by a heavy swinging pendulum, is made to blow a stream of air towards the centre of the fire, and being there obstructed by a burning sod of turf, placed for that purpose, the air is driven in all directions through the fuel; and thus is established an equal heat, as well as an equal blast, to carry off the sulphureous vapours through the chimney which surmounts the hearth. Lime, which ought to be very small in quantity, is occasionally thrown on to coagulate the slag; the melted lead trickles down to the well, which soon fills, and which ought to be allowed to remain full. New portions of lead will cause the well to overflow, and the melted metal will run down a gutter made in an attached inclined plane, called the apron, and thence into an iron pot placed beneath. The fire, after the charge has been smelted, is drawn out on the apron; the slags are picked out as soon as visible, and the fire is returned to its

place with more fuel; the bellows is worked; more ore is thrown in; and this process, being continually repeated, constitutes the working of the blast-hearth. The slags, when enough has been collected, are transferred to the slag-hearth for a product of hard lead, as already described.

" In the blast-hearth, the current of air from the bellows, delivered in the centre, is made to circulate by the skill of the workman, and it is the test of a good smelter that he compels the blast to permeate the burning fuel equally in all parts, without overheating the furnace. No sulphureous fumes issue but for a short while after the fire has been roused and opened, and it is during this period that the lead runs; hence the process is slow. In the reverberatory furnace the current is voluminous and diffused; the sulphureous vapours are therefore carried off abundantly, and the lead is reduced with proportionate rapidity. Extent of exposure to the current even, in some degree, compensates deficiency of heat; and so much is this the case that lead ore spread out extensively in the sun's rays will, as I was assured by an eminent smelter, exhale fumes of sulphur, and consume less fuel in the subsequent smelting. It is in this very particular that the blast-hearth is deficient: a previous preparative desulphuration, in a small furnace, is practised in some places where the blast-hearth is used.

" The facility with which the slag is removed from the surface of the melted matter is a great recommendation of the reverberatory furnace: in the blast-hearth this can only be done by drawing out the fire on the iron apron, and letting it cool somewhat until the masses of slag can be seen in order to be picked out. The fuel is then returned into the well, and time is lost before it resumes its heat.

" In the blast-hearth, unless there be a horizontal flue, there is no small waste, by evaporation of both sulphuret of lead and of lead in the metallic state. But in the reverberatory both are detained in the horizontal flue and the high

chimney or tower. The superintendent of an extensive mining locality assured me that an ore, which by assay was proved to contain 80 per cent. of metallic lead, would afford 74 per cent. in the reverberatory furnace, and only 64 per cent. in the blast-hearth.

" Notwithstanding this weight of evidence against the blast-hearth, it is not without its advantages. In inland situations, where land-carriage and consequent high price of fuel and other materials renders economy in these articles a countervailing consideration against the smaller produce of lead, the blast-hearth is a resource not to be contemned. When the supply of ore is not abundant, a reverberatory furnace would work to a great disadvantage: in such case the blast-hearth is, of course, to be preferred.

" There are some ores of so refractory a nature that the reverberatory furnace is very tardy in delivering its run of lead, although at length it gives such good produce: meanwhile expenses are accumulating. The ore raised from what in Flintshire is called a *blue stone*, which includes schist, mica-slate, and clay-slate, is much more refractory than what is raised from a white stone, that is, limestone: when raised from flint-stone the smelting becomes exceedingly difficult, and the quality of the lead produced is generally bad. In some such cases the blast-hearth has the advantage. A remarkable instance of this kind occurred at the Wheal-Betsy Mine, within five miles of Tavistock, in Devonshire. The ore obtained in that mine was refractory, and could with difficulty be smelted: the reverberatory furnace, in fact, might be said to have failed. The blast-hearth was then tried, and a produce, which corresponded much better with the assay, was obtained. The ore was, however, partially desulphurated in a small reverberatory, before it was transferred to the blast-hearth. Mr. Sadler says that two good smelters will smelt at the blast-hearth six bings of good ore a day, which are equal to about two tons eight cwt., short weight, that is, 5376 lbs.

" In the blast-hearth process a good deal of turf may be used in conjunction with coal, and this is a very great advantage in bog districts. The black turf of Ireland is capable of affording an intense heat, and may yet contribute to prove that our natural advantages are not of less account than those of other countries. The quantity of coal consumed in the blast-hearth is by much less than what is required for the reverberatory, and this is one of the chief recommendations of the former. Another is the very small comparative cost at which a compact smelting establishment may be constructed on the blast-hearth principle, and which, nevertheless, will be capable of doing a great deal of work. The long horizontal flue may be dispensed with; some lead in consequence will be lost, but no small outlay will be saved. Much space is also saved by the blast-hearth. There is a great advantage in smelting on the spot where the ore is raised: expense may, in certain localities, be saved, which would otherwise be incurred by the transport of the ore to one of the great smelting establishments. The mine proprietor will thus have a twofold source of profit. It is not possible to come to any positive conclusions on the comparative advantages of the two furnaces without taking into account local circumstances; it were an attempt to compare things that are not comparable. There is a trite saying amongst smelters that 'the blast-hearth saves coal and wastes lead;' and although this is true, yet, as Bishop Watson observes, 'a great quantity of metal, extracted at a great expense, may not produce so much clear profit as a less quantity procured at an easier rate: there is a beneficial limit between the quantity to be obtained and the expense attending the operation, which nothing but experience can ascertain.'

" On an occasion when it was necessary for me to come to a conclusion on the subject of this comparison, I made experiments intended to ascertain the quantity of lead producible from a given weight of ore, and also the cost of its production. The experiments were made with every precaution I could

think of to insure accuracy, and I watched every step of the process, in order to avoid all sources of mistake or uncertainty.

" Two ores of lead, both of them galenas, but very different in their qualities, are found in the valley of Glenmalure, in the county of Wicklow; one a steel-grained, hard kind, very refractory in the fire, taken out of an exceedingly hard quartz; the other of a softer nature, more easily reducible to the metallic state, and either plumose or cubical in its fracture. I shall distinguish these varieties by the names of hard and soft ores.

" A heap of hard ore, weighing one ton, was exceedingly well mixed with the shovel. A heap of soft ore, also weighing a ton, was equally well mixed, and kept separate from the former. These were intended to be separately smelted. The blast-hearth being filled with its proper fuel, and now at a sufficient heat, ore not taken from either of the heaps intended for the experiment was occasionally thrown on the fire, and worked in the usual manner, until the well of the furnace was filled with melted lead, and began to run down the gutter of the apron, or, in technical language, until we had a *running sump*. Without this precaution, whatever lead would be procured in the subsequent smelting process might be attributed to the greater or less overflow of the sump, owing to greater or less pressure of fuel on the surface of the melted metal. This method was further corrected by ascertaining the number of inches which the lead fell in the sump, in each case, after the fire had been removed from its surface at night. Those who are conversant with smelting operations will readily understand me. The height and quantity of the superincumbent fuel pressing on the surface of the melted lead, at the moment when the sump began to run, was accurately observed; so that by leaving off with the same quantity of fire, the weight pressing on the melted lead was the same as at the commencement of the process, and thus no part of the

lead produced could be attributed to an undue overflow of the sump. Care was also taken to exhaust the fuel burning in the hearth of all the lead furnished by the ore employed for producing a running sump, before any of the ore to be experimented on was thrown into the fire; and the same caution was observed in exhausting the fuel of its lead at the conclusion of each experiment. The fire left at the end of one process was used as fuel at the beginning of the next.

" All these preliminaries being arranged, and a running sump established, ore from one of the heaps was thrown on the fire at intervals; lime was occasionally sprinkled on to thicken the slag; and the smelting was continued in the usual manner, with a good blast, well circulated, until the whole ton had passed through the furnace, and the first run obtained.

" The slags were then transferred to the slag-hearth, and again smelted. The second slags were neglected, although in the great smelting-houses they are ground in a crushing-mill and buddled, and lead in grains is obtained in remunerating quantity. I had not means at my disposal for doing this, and hence my produce appears to a slight disadvantage. The ashes with which the slag-hearth had been filled were buddled, and some lead in small lumps procured. Both heaps of ore, viz., the soft and the hard, were subjected to the same treatment, and their lead extracted.

" I now proceed to state the cost of smelting one ton (of 2240 lbs.) of refractory ore, cut from a hard rock, laid down at the blast-hearth.

	s.	*d.*
Coals, carriage included (2 cwt.), ...	3	0
Coke, &c., ...	2	1
Lime (2 cwt.), ...	2	0
Turf (156 sods), ...	0	7½
Wages of ore-smelter, at 13*s.* per ton of lead,	6	7
Wages of slag-smelter, at 70*s.* per ton of lead,	2	6
	16	9½

This is the first cost of materials and wages for producing

	cwts.	qrs.	lbs.
Ore-lead, ...	10	0	22
Slag-lead, ...	0	2	24
	11	1	4

Cost of smelting one ton of soft ore cut from a soft rock:

	s.	*d.*
Coals (1¼ cwt.), ...	1	10½
Coke, ...	2	0
Lime (1 cwt.), ...	1	0
Turf (123 sods), ...	0	6
Wages of smelter, at 12*s.* per ton of lead, .	7	5
Wages of slag-smelter, at 70*s.* per ton of lead,	2	0
	14	9½

This is the first cost of materials and wages for producing

	Cwts.	qrs.	lbs.
Ore-lead, ...	12	1	3
Slag-lead, ...	0	2	5
	12	3	8

" The whole of the produce may be commercially considered as ore-lead; for the smelter is allowed to send to market one-tenth of slag-lead, yet it will all rate as ore-lead.

" For the sake of distinguishing the results, I caused the two heaps of ore to be smelted separately. Had they been smelted together in a state of mixture it is well known that the produce would have been greater, and at a less cost, as one ore acts a flux to another; and in the great smelting establishments the practice is to mix the different qualities. The arithmetical mean of my two results is 12 cwt. 12 lbs. of lead from one ton of mixed ore: but we may take it at least 12½ cwt., or 62½ per cent., had they been smelted together, at a cost of 15*s.* per ton of mixed ore. Hence, to produce one ton of pig-lead, 32 cwt. of ore should have been smelted,

which would have cost, for materials and wages, 24*s*. If we assume the price of the mixed oré at £10 per ton, the cost of 32 cwt., with that of smelting it, will be £17 4*s*., and the produce one ton of pig-lead.

" We have now to consider what would be the produce of this ore had it been smelted in the reverberatory; and first, it is necessary to refer to its assay. The assay masters adopt different methods: sometimes they use fluxes; sometimes they dry the ore; but the most usual practice, and that most relied on by the smelters, who purchase on the faith of the assay, is to test the ore in the same moist state in which it is brought direct from the heaps, and without any flux, in order that the assay process may more nearly represent the process of the smelter. I therefore adopted this last method. Ten ounces of the mixed ore were melted in an iron crucible, and treated in the usual manner. In this process, all the sulphur that the conjoint action of heat and air is inadequate to expel, was abstracted by the affinity of the iron of which the crucible is made, and on this account a new crucible answers best. The button of reduced lead weighed 7 oz. 11 dwts., or very nearly. This would indicate 75 per cent. of metal, but as the assay produce is never realized by the reverberatory, the actual return would be about 70 per cent. of lead; and 71 per cent. was the average produce at a great smelting-house in Wales, from ores amounting in the aggregate to 36,000 tons. At another house the average was 75 per cent. Other trials returned 67.5 per cent., and sometimes only 50. According to Bishop Watson, the Derbyshire smelting-houses averaged but 67 per cent. It is probably about the truth to assume that the ores on which I experimented would have returned 70 per cent. in the reverberatory.

" At this rate, in order to produce one ton of pig-lead, it would be necessary to smelt 28½ cwt. of ore, which, at £10 per ton, would be £14 5*s*. The cost of smelting in Flintshire, by the reverberatory, may be averaged at 30*s*. per ton

(2400 lbs.) of ore; hence the cost of smelting 28½ cwt. would be £2, and the expense of producing one ton of pig-lead by the reverberatory would be £16 5*s*. The comparison stands thus:—

	£	*s*.	*d*.
One ton of pig-lead obtained by the blast-hearth would cost	17	4	0
One ton of pig-lead obtained by the reverberatory	16	5	0
	0	19	0

" According to this calculation, other things being alike, pig-lead obtained by the blast-hearth would cost 19*s*. per ton more than the same lead obtained by the reverberatory furnace. Such, at least, is the result of my trials. But in Mr. Sadler's account of lead-smelting he states that 'two men will smelt about six *bings* (5376 lbs.) of good ore a day, and from thence produce 24 pigs of lead, each weighing 154 lbs.;' that is, 68·7 per cent. If this estimate be admitted, in order to produce one ton of pig-lead we must smelt 29½ cwt. of ore, which, at £10 per ton, would cost £14 17*s*. 6*d*.; its smelting, by the reverberatory, £2 4*s*. 3*d*.; and the expense of producing one ton of pig-lead would be £17 0*s*. 7*d*. The comparison would then stand thus:

	£	*s*.	*d*.
One ton of pig-lead, by the blast-hearth, would cost, ...	17	0	7
One ton of pig-lead, by the reverberatory, . .	16	5	0
	0	15	7

" Thus the balance against the blast-hearth would be 3*s*. 5*d*. per ton of lead less than in my estimate. It is, therefore, a true aphorism that the blast-hearth saves coal and wastes lead. But we must place to its credit several advantages. The comparatively small cost of a blast-hearth, which would do all the work of a small mining concern, is to be considered; any small house, with a good chimney, can be made

to answer: I have known smelting, by the blast-hearth, to a large amount, to be carried on in one of the streets of Dublin. We must also remember that, by smelting on the spot where the ore is raised, much expense is saved in the carriage of materials and produce. And it is a fact that some refractory ores are more easily smelted in the blast-hearth than in the reverberatory. On the whole, there is little use in endeavouring to come to a determination of the comparative merits of these two furnaces, in the abstract, without reference to the locality. The decision of the question must depend on the circumstances of the place; sometimes one furnace will be preferable, sometimes the other.

"I can adduce a case in point of the advantageous employment of a blast-hearth at a mine where the reverberatory furnace could not be maintained for want of a sufficient supply of ore, and the only alternative was exportation. When the Glenmalure lead mine (County Wicklow) was in brisk operation some years since, the following were the estimates of smelting on the spot, and exporting it to the nearest market:—

	£	*s.*	*d.*
Cutting out the ore from the rock, per ton, . .	3	17	6
Royalty (as it should have been), ...	1	10	0
Dressing, ...	0	16	0
Smelting, by the blast-hearth, ...	0	17	9
	7	1	3

"The produce was 12 cwt. 3 qrs. 8 lbs. of pig-lead; its carriage to Dublin, 13*s.* 8*d.*, added, made its cost £7 14*s.* 11*d.* in Dublin; but there it was sold for £9 12*s.* 4*d.*, leaving a profit of £1 17*s.* 5*d.* per ton of ore. Had the same ore been exported to Dee-bank, the additional charge of carriage to Wicklow, storage, freight, insurance, two commissions, and an assay, would increase the first cost of the ore to £7 6*s.* 4*d.*, while the price obtainable at Dee-bank was but £8 17*s.* 6*d.*;

the profit would therefore be £1 11*s.* 2*d.*, leaving a balance in favour of smelting the ore by the blast-hearth of 6*s.* 3*d.* per ton of ore, or an increased profit of nearly 17 per cent. If Mr. Sadler's estimate be adopted, the balance would be three times this sum.

"On the whole, I think it fair to conclude that the reverberatory furnace makes larger returns of lead; that where the produce of ore is inadequate to the supply of a reverberatory furnace, or where the cost or carriage of fuel and other materials is high, the blast-hearth is not without its advantages; that it is in vain to inquire, in the abstract, which is the more profitable furnace, as the decision of the question entirely depends on the circumstances of the locality."

April 24th, 1848.

REV. HUMPHREY LLOYD, D. D., PRESIDENT, in the Chair.

THE Rev. Charles Graves made a communication respecting Mathematical Expressions for Hypothetical and Disjunctive Propositions.

Adopting the principles and notation furnished by Mr. Boole in his "Application of Analysis to Logic," Mr. Graves suggests that it would be more in accordance with the ordinary use of language to express the hypothetical proposition,

If X be true, Y is true,

by the equation

$$x = vy, \tag{1}$$

than by that which Mr. Boole has employed, viz.

$$x(1-y) = 0. \tag{2}$$

In the former of these equations the symbol x selects all the cases in which the antecedent X is true, whilst y selects